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A comparison of actual to estimated weights in Australian children attending a tertiary children's' hospital, using the original and updated APLS, Luscombe and Owens, Best Guess formulae and the Broselow tape☆

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ABSTRACT

Introduction: During paediatric resuscitation it is essential to be able to estimate the child's weight as it determines drug doses and equipment sizes. Age and length-based estimations exist, with age-based estimations being especially useful in the preparation phase and the length-based Broselow tape having weight-based drug doses and equipment already assigned via a colour code system. The aim of this study was to compare the actual recorded weights of Australian children to the predicted weights using the original and updated APLS, Luscombe and Owens and Best Guess formulae and the Broselow tape.
Method: A retrospective observational study of children attending an Australian tertiary children's hospital.
Results: From 49,565 patients extracted from the database, 37,114 children with age and weight and 37,091 children with age and height recorded were included in the analysis. Best Guess was the most accurate, with the smallest overall mean difference 0.86 kg. For <1 year old, Broselow tape was the most accurate (mean difference −0.43 kg), Best Guess was the most accurate for ages 1–5 years and 11–14 years (mean difference 0.27 and 0.20 kg respectively), and the updated APLS formula was the most accurate for 6–10 year-old (mean difference 0.42 kg). The Broselow tape was able to only classify 48.9% of children into the correct weight colour band.
Conclusions: For an age-based weight estimation, in infants less than one year the new APLS formula is the most accurate and over one year the Best Guess formulae should be used.
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1. Introduction

In paediatric resuscitations, many interventions are calculated based on the weight of the child, including medication doses, intravenous fluid requirements, defibrillation energy doses and equipment sizes. Ideally the child must be weighed; however, this is not always possible in the context of emergency management such as during resuscitation or trauma as the child is unable to be placed on scales. Furthermore, it is advantageous to have weight predicted before an acutely unwell child arrives in the resuscitation room in order to prepare the correct drugs and equipment. Medical professionals are not proficient at accurate weight estimations,[1,2] and thus, there is a need for precise methods with which to estimate weight.

There are various tools for paediatric weight estimation that have been proposed and these are based on either age or length of the patient.[3–8] The most well-known method is the original advanced paediatric life support (APLS) formula,[7] which is based on age. It became apparent that the APLS formula tended to underestimate the actual weight and the margin of error increased with age.[4,9,10] Following this, Luscombe and Owens developed a new formula[4] which had been found to be more accurate than APLS.[11] In addition, an Australian formula known as Best Guess had also been developed which was more accurate than APLS.[5] In the most recent edition of the APLS guidelines, three new formulae were presented, stratified by age brackets[6] using the original APLS for ages 1–5 years and the Luscombe and Owens formulae for ages 6–12 years.

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Table 1
The ancestry of the population of Greater Western Sydney and New South Wales from census data.

Year	2011			2006			Change
Ancestry	Number in Greater Western Sydney	Greater Western Sydney (%)	New South Wales (%)	Number in Greater Western Sydney	Greater Western Sydney (%)	New South Wales (%)	2006–2011
Australian	476,290	24.8	32.1	512,623	28.7	36.2	−36,333
English	423,083	22.0	31.1	387,328	21.7	29.0	+35,755
Chinese	126,348	6.6	5.5	105,573	5.9	4.7	+20,775
Irish	118,811	6.2	9.6	108,079	6.0	8.8	+10,732
Lebanese	93,266	4.8	2.1	82,339	4.6	2.0	+10,927
Scottish	93,177	4.8	7.6	82,889	4.6	6.9	+10,288
Indian	81,415	4.2	2.0	57,033	3.2	1.5	+24,382
Italian	76,220	4.0	3.6	73,898	4.1	3.5	+2,322
Vietnamese	61,597	3.2	1.2	49,992	2.8	1.0	+11,605
Filipino	57,207	3.0	1.4	46,968	2.6	1.2	+10,239
German	41,128	2.1	3.1	39,662	2.2	3.0	+1,466
Maltese	38,323	2.0	0.9	37,000	2.1	0.9	+1,323
Greek	29,262	1.5	1.8	28,436	1.6	1.9	+826
Assyrian/Chaldean	20,189	1.0	0.3	15,943	0.9	0.3	+4,246
Croatian	19,511	1.0	0.6	18,924	1.1	0.6	+587

Excludes ancestries with less than 1% of the total Greater Western Sydney population.

There is increasing evidence that methods based on the length of the child are more accurate than aged-based formulae,[7,12] however, this requires accurate physical measurement and may require additional tools. The Broselow tape also lists drug doses and equipment sizes for resuscitation,[8] however, it may have a tendency to underestimate weight.[9]

The aim of this study was to compare the actual recorded weights of Australian children to the predicted weights using the original and updated APLS, Luscombe and Owens and Best Guess formulae and the Broselow tape.

2. Methods

2.1. Study design, setting and data

The Children's Hospital at Westmead (CHW) is located in Sydney, Australia and is a tertiary paediatric referral centre for New South Wales (NSW). We conducted a retrospective observational study with data extracted from the electronic medical record (Cerner Powerchart, Kansas City, MO) from February 1981 to January 2011 for patients who attended or were admitted to the hospital during this time.

Table 1 describes the local population served by CHW (Greater Western Sydney) and NSW in general. Ancestry from census data defines the cultural association and ethnic background of an individual going back three generations. Ancestry is a good measure of the total size of cultural groups regardless of where they were born or what language they speak [13]

Data extracted was age, weight and height/length and was the clinical measurement used for standard clinical care and entered directly into the medical record by the clinician.

Height was measured to the nearest mm and weight to two decimal places as standard.

All patients were initially extracted and then excluded due to age >14 years or corrupt data. Duplicate data records with matching medical record number (MRN), date of birth, height and weight were also removed.

Box plots of height and weight for each age group were used to identify potential outliers. The most extreme values for height and weight were deleted as supposed errors if they were more than 3 box lengths from the upper or lower edge of the box and if they were also separated from the remainder of the data. Data points that were outliers but were not separated from the remainder of the data were retained.

3. Weight estimation

The original APLS weight was computed as follows for ages 1–10 years:

Weight (kg) = (age + 4) × 2

The updated APLS weight was computed as follows for ages 0–12 years:

- Infants 0–12 months: weight (kg) = (0.5 × age in months) + 4
- Children 1–5 years: weight (kg) = (2 × age in years) + 8
- Children 6–12 years: weight (kg) = (3 × age in years) + 7

Luscombe and Owens was computed for ages 1–14 years as

Weight (kg) = (3 × age) + 7

Best Guess weight was computed as follows:

- Infants 1–11 months: weight (kg) = (age in months + 9)/2
- Children 1–4 years: weight (kg) = 2 × (age + 5)
- Children 5–14 years: weight (kg) = 4 × age

A current Broselow Pediatric Emergency Tape (2007, Edition B, Armstrong edical Industries, IL, USA) was purchased and measured to define the colour cut-offs. Children taller than the length of the tape were excluded from these estimates.

4. Data analysis

Data were analysed using SPSS version 19.0 (IBM, USA). Pearson's correlation was used to examine the relationship between weight and the methods of weight estimation.

Means and standard deviations (SD) of measured heights and weights by age were computed. For each child, weight was estimated from age or length for each reported weight estimation method and was summarised by age group. Estimated mean weights were plotted by age to compare relative absolute differences between the methods.

For each method, the mean difference, which was the mean of the difference between actual weight and the estimated weight (bias), and the 95% CI was computed using a paired samples *t*-test. The percent weight estimated for each method was computed as the calculated weight divided by the measured weight and multiplied by 100. For each method, children with a percent weight <90% were classified as being more than 10% below their measured weight and children with a percent weight >110% were classified

Table 2
Mean height and weight by age.

Age (years)	*n*	Height (cm)	Weight (kg)
		Mean (SD)	Median (IQ range)
0	294	59.48 (9.43)	5.68 (4.18)
1	318	77.25 (6.94)	10.14 (3.00)
2	530	87.46 (7.14)	12.79 (3.36)
3	842	96.06 (7.33)	15.30 (4.00)
4	1204	103.20 (8.14)	17.20 (4.66)
5	1531	109.73 (8.20)	19.30 (5.46)
6	1924	116.00 (8.48)	21.60 (6.37)
7	2519	122.07 (8.84)	24.38 (7.68)
8	3127	127.68 (9.61)	27.40 (9.92)
9	3657	133.52 (9.66)	31.20 (13.30)
10	4020	138.74 (10.02)	35.20 (15.48)
11	4231	144.37 (10.38)	39.30 (17.58)
12	4312	149.53 (11.27)	44.42 (20.20)
13	4414	154.57 (11.36)	49.10 (21.30)
14	4191	159.20 (11.39)	54.00 (20.86)

as being more than 10% above their measured weight. For each of the methods, the number of children whose estimated weight was less than 10% below or more than 10% above their measured weight was computed (precision).

5. Results

5.1. Participants

Data from 49,565 patients were initially extracted. 1395 records from 1981 to 2000 (2.8%) and the rest post 2000. 10,323 patients were excluded due to age >14 years or corrupt data and 2083 had duplicate records.

Outliers excluded 28 height and 17 weight records leaving 37,114 children with valid age and weight recorded and 37,091 children with a valid age and height recorded.

There were 12,688 patients whose length was within the range able to be tested against the Broselow tape.

The study population included 20,227 males (54.5%). The mean measured height and weight for each age group is shown in Table 2. In the data set for children from 0–14 years, the absolute range of measured weights was from 1.75 to 156.20 kg. The absolute range of measured heights was 41.0–199.2 cm.

6. Main results

All methods of weight estimation had a strong positive relationship with measured weight (Pearson's correlation $R = 0.63–0.81$), with the Broselow tape having a very strong positive relationship ($R = 0.81$).The estimated weight for each age-based method and the difference between estimated and actual weight is shown in Fig. 1. Broselow was not included in this graph as age is not used as part of the estimate and therefore, there is no estimated weight for age, only an estimated weight for length. The margin of error for the original APLS increased with age. Best Guess had smaller differences between the estimated weight and the mean weight for children aged 11–14 years than Luscombe and Owens.

The mean difference between estimated weights is shown in Table 3. All methods except Best Guess tended to underestimate weight with a mean difference from −1.14 to −5.76 kg. Best Guess was the most accurate, with the smallest overall mean difference 0.86 kg. In the <1 year age bracket, Broselow tape was the most accurate (mean difference −0.43 kg), Best Guess was the most accurate in the age brackets 1–5 years and 11–14 years (mean difference 0.27 and 0.20 kg respectively), and the updated APLS/Luscombe formula was the most accurate in the 6–10 year bracket (mean difference 0.42 kg). In summary, the most accurate formulae were:

- Infants <1 year: weight (kg) = (0.5 × age in months) + 4
- Children 1–5 years: weight (kg) = 2 × (age in years + 5)
- Children 6–10 years: weight (kg) = (3 × age in years) + 7
- Children 11–14 years: weight (kg) = 4 × age in years

Broselow had the largest number estimated to within 10% of their actual weight, 49.4%.

The Broselow tape was able to classify 48.9% of children into the correct weight band (Table 4). The Broselow tape correctly classified more than half of the small children, i.e. those falling in the 3–5, pink and red categories, and the mid-range children in the yellow, white and blue categories. In the tallest category, green, almost half of the children had their weight underestimated: the mean weight for the green group was 38 kg.

A subgroup analysis was performed with only children who could be measured by the Broselow tape. In this case, the updated APLS and Luscombe and Owens had a smaller mean difference than the Broselow tape (1.89, 2.87 and −3.08 respectively).

7. Discussion

To our knowledge, this paper is one of the first to study the updated APLS formulae and is one of the largest studies comparing methods of paediatric weight estimation. We found Best Guess to be the most accurate overall (mean bias 0.86 kg); however, Broselow was the most precise (49.4% within 10%). In particular, Best Guess was the most accurate in the age groups 1–5 years and 11–14 years.

For infants <1 year, the updated APLS was more accurate than Best Guess, the only other age-based formulae for this group (mean difference 0.51 kg vs. 0.98 kg).

These results support the change that APLS has made to its formulae. However, having to recollect multiple formulae can be problematic[14] and in this population the combination of APLS for the <1 year and Best Guess for 1–14 years seems to be the best compromise (rather than have four formulae) and challenges the notion that Broselow is more accurate than aged-based formulae.[7,12,15]

The Broselow tape was less accurate than three of the aged-based formulae: updated APLS, Luscombe and Owens, and Best Guess. The Broselow tape correctly classified just under half of our population, with over a third having their weight underestimated and the remaining overestimated. Clinicians need to be aware that the Broselow tape is the most precise in estimating weight to within 10% of actual weight but is not the most accurate and will misclassify the Broselow colour up to 60% of the time with increasing likelihood with increasing age. This may have important clinical implications as clinicians may use the wrong drug doses, leading to ineffective treatment or over treatment and toxicity as well as complications from the use of the wrong equipment sizes.

This study is consistent with previous studies, where Broselow has been shown to underestimate weight,[9,16] and that whilst Broselow is more precise, Best Guess is more accurate.[17] A recent study in South Africa[7] found the original APLS to be more accurate than we did. However, this population is regarded as a (rapidly) developing country and perhaps these findings are not generalisable to an Australian paediatric population.

Our population for this study was hospital attendees at a paediatric tertiary hospital. These children's' ancestry has already defined in the study methodology and represents a varied ethnic mix that should be considered when applying these results to other settings. The relatively small number of children presenting to the hospital with growth or stature abnormalities is unlikely to have skewed our data. We feel that the large sample size makes the study relevant and in particular is the population that is likely to attend any tertiary children's hospital for emergency care. The Australian

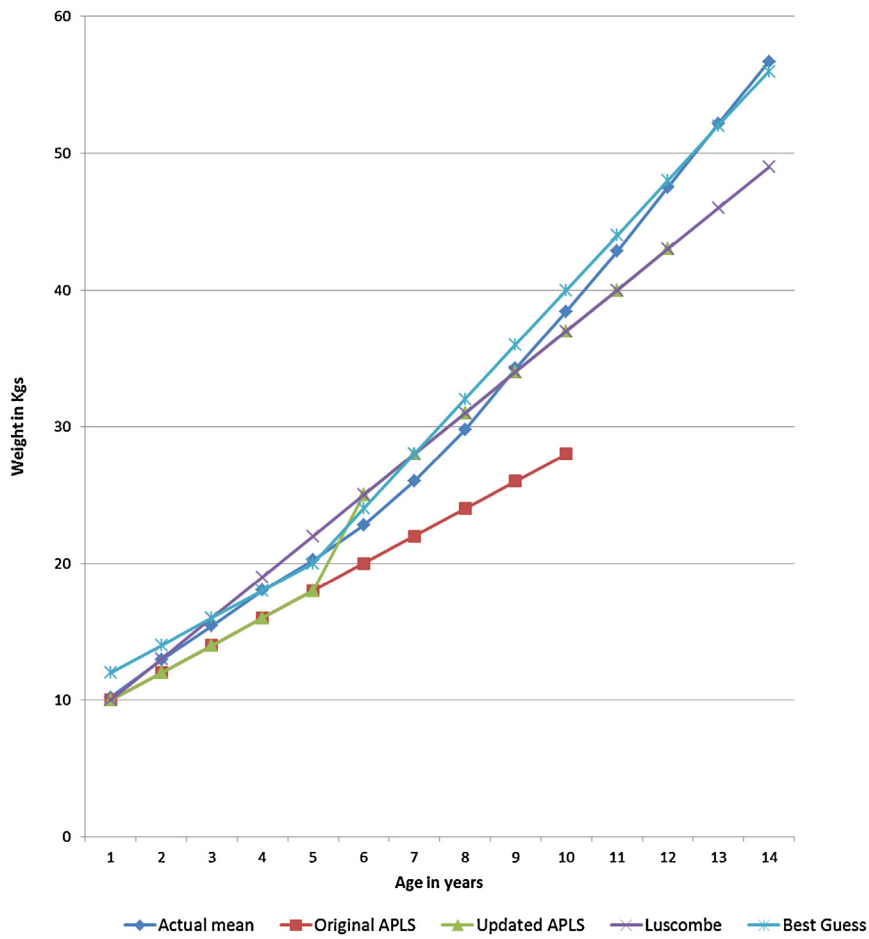

Fig. 1. Measured mean weight versus estimated weight for each age-based method, stratified by age in years.

population has diverse ethnicity and thus, the varied demographic gives rise to serious challenges when trying to use aged-based formulae as has been found in Pacific Islander and Maori children.[18] We were unable to differentiate between ethnicities in this study as the data did not have that recorded. A recent study developed a novel length-based estimation tool that included a modification based on habitus, and this was found to be more accurate than the Broselow tape.[19] As habitus was not recorded in our study, we did not examine this new tool, but it could be considered in future studies, particularly in populations with diverse body habitus. The data was extracted over a 30 year period and therefore, there may be longitudinal changes in population height and weight which may

Table 3
Mean difference of each method from child's actual weight and accuracy of estimated weights.

Age group		<1 year	1–5 year	6–10 year	11–14 year	Overall
APLS	*N*	–	4425	15246	–	19671
Original[a]	Mean difference (kg)	–	−1.73	−6.92	–	−5.76
	(95% CI)		(−1.88, −1.58)	(−7.10, −6.75)		(−5.90, −5.62)
	% within 10%	–	35.5%	27.2%	–	29.0%
APLS	*N*	294	4425	15246	8543	28508
Updated[b]	Mean difference (kg)	0.51	−1.73	0.42	−3.68	−1.14
	(95% CI)	(0.35, 0.67)	(−1.88, −1.58)	(0.25, 0.59)	(−4.00, −3.35)	(−1.28, −1.00)
	% within 10%	33.3%	35.5%	23.4%	22.7%	25.1%
LO	*N*	–	4425	15246	17148	36819
	Mean difference (kg)	–	0.97	0.42	−5.30	−2.18
	(95% CI)		(0.83, 1.12)	(0.25, 0.59)	(−5.55, −5.05)	(−2.32, −2.04)
	% within 10%	–	33.7%	23.4%	24.0%	25.5%
Best Guess	*N*	219	4425	15246	17148	37039
	Mean difference (kg)	0.98	0.27	1.77	0.20	0.86
	(95% CI)	(0.74, 1.21)	(0.12, 0.42)	(1.60, 1.94)	(−0.05, 0.45)	(0.72, 0.99)
	% within 10%	29.7%	36.2%	22.4%	23.5%	24.6%
Broselow	*N*	294	4421	14028	5683	24426
	Mean difference (kg)	−0.43	−1.41	−3.26	−4.09	−3.08
	(95% CI)	(−0.55, −0.31)	(−1.51, −1.31)	(−3.37, −3.14)	(−4.30, −3.87)	(−3.17, −3.00)
	% within 10%	47.3%	55.7%	49.7%	43.8%	49.4%

[a] Age 1–10 only.
[b] Age 0–12 years only.

Table 4
Broselow tape colours showing the percent correctly classified or under or over estimated.

Colour	*N*	Over-estimated by 2 or more (%)	Over-estimated by 1 (%)	Correctly classified (%)	Under-estimated by 1 (%)	Under-estimated by 2 or more (%)
3–5	159	–	19.5[a]	72.3	8.2	0.0
Pink	98	0.0	16.3	60.2	20.4	3.1
Red	165	0.6	26.1	55.2	17.0	1.2
Purple	417	4.1	27.1	44.6	22.3	1.9
Yellow	1252	2.2	14.4	55.6	26.1	1.8
White	2524	0.5	13.4	59.1	22.9	4.1
Blue	4077	0.5	15.8	59.0	19.5	5.2
Orange	6507	0.5	18.4	49.5	21.9	9.7
Green	9161	0.5	14.9	39.8	44.8[a]	–
Total	24360	0.6	16.1	48.9	30.3	4.0

[a] Off the chart so unable to distinguish between under/over-estimation by 1 and 2 or more.

have influenced the data. However, over 97% of the records came since 2000 which should negate this confounder.

The accurate estimation of a child's weight continues to be important during resuscitation as even with the advent of new equipment such as trauma stretchers that allow the measurement of a child's weight, it is not always possible particularly in cases of lower Glasgow coma scores, during the use of immobilisation equipment, in children undergoing CPR and those with more severe injuries.[20] Therefore, further work is required to estimate ideal body weight and identify in what situations ideal body weight should be used to calculate medication doses rather than actual body weight (estimated or weighed) which was beyond the scope of this study.

8. Conclusions

Where an immediate weight cannot be obtained this study suggests, for an age-based estimation, in infants less than one year the new APLS formula is the most accurate and over one year the Best Guess formulae should be used. The Broselow tape, whilst being the most precise, may misclassify up to 60% of children into a different colour group, with a greater risk in older children.

References

1. Greig A, Ryan J, Glucksman E. How good are doctors at estimating children's weight? J Accid Emerg Med 1997;14:101–3.
2. Harris M, Patterson J, Morse J. Doctors, nurses, and parents are equally poor at estimating pediatric weights. Pediatr Emerg Care 1999;15:17–8.
3. Advanced Life Support Group. Advanced paediatric life support: the practical approach. 4th ed. London: BMJ Publishing Group; 2005.
4. Luscombe M, Owens B. Weight estimation in resuscitation: is the current formula still valid? Arch Dis Child 2007;92:412–5.
5. Tinning K, Acworth J. Make your Best Guess: an updated method for paediatric weight estimation in emergencies. Emerg Med Australas 2007;19:528–34.
6. Advanced Life Support Group. Advanced paediatric life support: the practical approach. 5th ed. UK, Chichester: John Wiley & Sons Ltd.; 2011.
7. Geduld H, Hodkinson PW, Wallis LA. Validation of weight estimation by age and length based methods in the Western Cape: South Africa population. Emerg Med J 2011;28:856–60.
8. Lubitz DS, Seidel JS, Chameides L, Luten RC, Zaritsky AL, Campbell FW. A rapid method for estimating weight and resuscitation drug dosages from length in the pediatric age group. Ann Emerg Med 1988;17:576–81.
9. Argall JA, Wright N, Mackway-Jones K, Jackson R. A comparison of two commonly used methods of weight estimation. Arch Dis Child 2003;88:789–90.
10. Luscombe M. 'Kids aren't like what they used to be': a study of paediatric patient's weights and their relationship to current weight estimation formulae. Brit J Anaesth 2005;95:578P–9P.
11. Kelly AM, Nguyen K, Krieser D. Validation of the Luscombe weight formula for estimating children's weight. Emerg Med Australas 2011;23:59–62.
12. Black K, Barnett P, Wolfe R, Young S. Are methods used to estimate weight in children accurate? Emerg Med (Fremantle) 2002;14:160–5.
13. Australian Bureau of Statistics. Census of Population and Housing 2006 and 2011. http://profile.id.com.au/wsroc/ancestry?BMID=40&WebID=200.(accessed 6th November 2013).
14. Marikar D, Varshneya K, Wahid A, Apakama O. Just too many things to remember? A survey of paediatric trainees' recall of advanced paediatric life support (APLS) weight estimation formulae. Arch Dis Child 2013;98:921.
15. So TY, Farrington E, Absher RK. Evaluation of the accuracy of different methods used to estimate weights in the pediatric population. Pediatrics 2009;123:e1045–51.
16. Park J, Kwak YH, Dok Kim. A new age-based formula for estimating weight of Korean children. Resuscitation 2012;83:1129–34.
17. Nieman CT, Manacci CF, Super DM, Mancuso C, Fallon Jr WF. Use of the Broselow tape may result in the underresuscitation of children. Acad Emerg Med 2006;13:1011–9.
18. Theron L, Adams A, Jansen K, Robinson E. Emergency weight estimation in Pacific Island and Maori children who are large-for-age. Emerg Med Australas 2005;17:238–43.
19. Wells M, Coovadia A, Kramer E, Goldstein L. The PAWPER tape: a new concept tape-based device that increases the accuracy of weight estimation in children through the inclusion of a modifier based on body habitus. Resuscitation 2013;84:227–32.
20. Sinha M, Lezine MW, Frechette A, Foster KN. Weighing the pediatric patient during trauma resuscitation and its concordance with estimated weight using Broselow Luten emergency tape. Pediatr Emerg Care 2012;28:544–7.